PCT Application No. PCT/EP00/06772. The Preliminary Amendment also adds new claims 20-38. The new claims conform the claims to U.S. Patent and Trademark Office rules and do not add new matter to the application.

In accordance with 37 C.F.R. § 1.121(b)(3), the Substitute Specification (including the Abstract, but without the claims) contains no new matter. The amendments reflected in the Substitute Specification (including Abstract) are to conform the Specification and Abstract to U.S. Patent and Trademark Office rules or to correct informalities. As required by 37 C.F.R. § 1.121(b)(3)(iii) and § 1.125(b)(2), a Marked Up Version Of The Substitute Specification comparing the Specification of record and the Substitute Specification also accompanies this Preliminary Amendment. Approval and entry of the Substitute Specification (including Abstract) are respectfully requested.

The underlying PCT Application No. PCT/EP00/06772 includes an International Search Report, dated December 18, 2000, and an International Preliminary Examination Report, dated November 20, 2001, copies of which are submitted herewith.

Applicants assert that the subject matter of the present application is new, non-obvious, and useful. Prompt consideration and allowance of the application are respectfully requested.

Respectfully Submitted,

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REFLECTION [MATERIAL MEASURE]-TYPE GRADUATION AND METHOD FOR [PRODUCING] MANUFACTURING A REFLECTION [MATERIAL MEASURE]-TYPE GRADUATION

Field of the Invention

The present invention is directed to a [reflectometer] reflection-type graduation, as well as to a method for manufacturing a [reflectometer] reflection-type graduation.

[Optical incident-]Related Technology

Reflected-light position [-measuring devices] encoders usually include a [reflectometer] reflection-type graduation, as well as a scanning device that is movable [relatively thereto. Typically] relative to the reflection-type graduation. A light source is typically mounted at the scanning device [is a light source, which emits a bundle of light] that emits a light beam in the direction of the [reflectometer. From there, the light bundle] reflection-type graduation. From the reflection-type graduation, the light packet is reflected back toward the scanning device, where it is modulated [in dependence] dependent upon displacement[,] to pass through[, as the case may be, one or a plurality of] one or more graduated-scale scanning structures, and is ultimately [be] measured by [an opto-electronic detector system] a sensing array. The signals generated in this manner, and modulated in dependence upon displacement, are then further processed [via] by a downstream evaluation unit.

[Known reflectometers of such systems] Reflection-type graduations are typically made of a substrate material, upon which subsections having different optical properties are placed in alternating sequence. In the case of an incremental graduation, the array of the various subsections extends in the direction of measurement. It can be provided, for example, to produce subsections of high and low reflectivity on a glass substrate. As a substrate material, steel is also [optionally] used, on which subsections having high and low reflectivity are [likewise] formed. In this connection, the subsections of high reflectivity can be made of gold[, while in]. The steel surface is etched to have a frosted texture for the subsections of lower reflectivity, [the steel surface is etched dull,] so that the incident light [there] is

absorbed or reflected diffusely [reflected].

A number of requirements are placed on material measuring standards of this kind. These include a greatest possible abrasion resistance, a high thermal resistance, defined thermal properties, as well as good long-term stability. However, the above-mentioned, known material measuring standards on glass and steel substrates only partially meet these requirements.

Summary of the Invention

An [The] object of the present invention is[, therefore,] to devise a [reflectometer] reflection-type graduation, as well as a method for manufacturing the same, [which will enable the requirements cited above to be optimally met.] having the greatest possible abrasion resistance, a relatively high thermal resistance, defined thermal properties, as well as relatively high long-term stability.

This objective is achieved by a reflection-type graduation having a silicon substrate. The silicon substrate has first subsections formed thereon. Each of the first subsections has etched oblique surfaces. The surfaces are positioned so that light beams directed incident to the surfaces cause no retroreflection. The substrate also includes second subsections having relatively higher reflecting properties as compared to the first subsections. The first subsections and second subsections are alternatively disposed on the substrate in a first direction [reflectometer having the features of Claim 1.

Advantageous specific embodiments of the reflectometer according to the present invention are derived from the measures specified in those claims which are dependent upon Claim 1].

The objective at hand is also achieved by a method for manufacturing a [reflectometer having the features of Claim 10.] reflection-type graduation by providing a silicon substrate; forming first subsections and second subsections that extend in a first direction on the silicon substrate, the first subsections and the second subsections having different optical reflecting properties; wherein, in the first subsections, a plurality of oblique surfaces is produced by deep etching, which are positioned such that no retroreflection of the light beams incident

thereto results.

[Advantageous specific embodiments of the method according to the present invention are derived from those claims which are dependent upon Claim 10.

It] As mentioned, it is provided in accordance with the present invention to employ a silicon substrate and to suitably form the subsections having different reflectivity thereon. Preferably, monocrystalline silicon is used. In this connection, the subsections having less reflectivity each include a plurality of oblique surfaces, which are produced by deeply etching the silicon substrate along different crystal directions [and which]. The surfaces are positioned such that no retro-reflection of light rays incident thereto results.

In one preferred specific embodiment of the present invention, the oblique surfaces are made up of V-shaped grooves, which extend in a direction [normal] perpendicular or parallel to that direction in which the subsections having different reflective properties are configured. As to the highly reflecting subsections, one may use the [subsections of the] bare silicon substrate surface[, not discussed further here, if indicated,] or it is also possible to coat these subsections with a suitable material.

[Alternatively] As an alternative to V-shaped grooves, the oblique surfaces in the subsections having low reflectivity may also be formed as deeply etched pyramid structures[; i.e., there]. There are[, accordingly,] various ways to produce the requisite oblique surfaces having the appropriate optical action. This variant is especially suited for material measuring standards having coarser graduation intervals.

A material measuring standard of this kind has a number of advantages. Cited in this connection are, first of all, the substantial resistance to abrasion, as well as the very high mechanical resistance of the surface of the material measuring standard. In addition, the preferably monocrystalline silicon substrate is structurally stable and no longer changes, i.e., no undesirable diffusion processes result. Furthermore, silicon possesses defined thermal expansion characteristics, which is especially significant for high-precision applications. Particularly beneficial is, for instance, the use of the material measuring standard according to the present invention in the semiconductor industry, since the position-measuring system in

question includes a material measuring standard which has the same thermal expansion coefficient as the semiconductor material to be processed. It should also be mentioned that, as a substrate material, silicon is [available] relatively [inexpensively] inexpensive in a defined state, i.e., in a stable quality with respect to impurities and surface quality. Also noted in this connection is the relatively [easy] high processability of this material.

The [reflectometer] reflection-type graduation according to the present invention may be used, of course, in many different position-measuring devices, i.e., in connection with the most widely varying scanning principles. It is, of course, likewise possible to use the [reflectometer] reflection-type graduation according to the present invention in linear measuring systems, as well as in rotary measuring systems or two-dimensional measuring systems[, etc]. In accordance with the present invention, the most widely varying material measuring standards are able to be produced, such as incremental graduations, code graduations, structures for reference marks, and so forth.

Brief Description of the Drawings

Further advantages of the present invention, as well as details pertaining thereto, are derived from the subsequent description of exemplary embodiments on the basis of the [enclosed drawing, whose] following figures [show]:

Figure 1 is a plan view of an exemplary embodiment of the [reflectometer] reflection-type graduation according to the present invention;

Figure 2 is an enlarged detail [from] of the reflection-type graduation of Figure 1;

Figures 3a is a [and 3b in each case,] sectional [views] view taken along line IIIa—IIIa of Figure 2;

Figure [4]3b is sectional view taken along line IIIb—IIIb of Figure 2;

Figure 4 is a sectional view of an individual V-[groove, into which a light beam is incident;] shaped groove of the reflection-type graduation shown in Fig. 3a, showing a light beam incident thereto;

[Figures 5a-5h in each case, individual method steps in the manufacturing of the reflectometer according to the present invention;] Figure 5a is a side view of a silicon substrate prior to processing for forming the reflection-type graduation of Figure 1;

[Figure 6] Figure 5b is a top view of a silicon substrate prior to processing for forming

the reflection-type graduation of Figure 1;

Figure 5c is a top view of a silicon substrate for forming the reflection-type graduation of Figure 1, with an etching mask applied on the substrate;

Figure 5d is a side view of a silicon substrate for forming the reflection-type graduation of Figure 1, with an etching mask applied on the substrate;

Figure 5e is a side view of a silicon substrate for forming the reflection-type graduation of Figure 1 being etched to form V-shaped grooves shown in Figure 3b;

Figure 5f is a side view of a silicon substrate for forming the reflection-type graduation of Figure 1 having been etched to form V-shaped grooves shown in Figure 3b;

Figure 5g is a plan view of a silicon substrate for forming the reflection-type graduation of Figure 1 having been etched to form V-shaped grooves shown in Figure 3b;

Figure 5h is a side view of a silicon substrate for forming the reflection-type graduation of Figure 1, after the etching mask has been removed from the substrate;

Figure 6 is a scanning electron-[microscopic picture] microscope image of a part of the [reflectometer] reflection-type graduation of the present invention in accordance with the first exemplary embodiment; and [elucidated above;]

Figure 7 is a scanning electron-[microscopic picture] microscope image of a part of a [reflectometer] reflection-type graduation of the present invention in accordance with a second exemplary embodiment.

Detailed Description

Figure 1 is a plan view of a first exemplary embodiment of the [reflectometer] reflection-type graduation in accordance with the present invention [which] that may be employed, for example, in a position-measuring device used for measuring linear displacements between two objects which are movable relatively to one another.

[Illustrated reflectometer] For this exemplary embodiment, reflection-type graduation 1 is essentially composed of an oblong silicon substrate 2 [which] that extends in measuring direction x and on which an incremental [scale-division] graduation track 3 is arranged [for this exemplary embodiment]. Incremental [scale-division] graduation track 3, in turn, is made up of first and second rectangular subsections 4a, 4b, which exhibit different optical reflecting properties for light incident thereto. Reference numeral 4a denotes the subsections of lower reflectivity; reference numeral 4b[, on the other hand,] denotes the subsections of

high reflectivity. Subsections 4a, 4b[, 4a] having low and high [and low] reflectivity are arranged in alternating sequence in a first direction x, which also corresponds to the measuring direction along which a relative displacement would be measured in a corresponding position-measuring device. Various subsections 4a, 4b are identically constructed with respect to their geometric dimensions. In first direction x, they have a width b; [normally] perpendicular thereto, in second direction y, they extend over length l, which, in this example, also corresponds to the width of incremental [scale-division] graduation track 3.

In this specific embodiment, subsections 4b, designed to reflect incident light bundles, are formed [by] on the surface of silicon substrate 2. In this instance, monocrystalline silicon substrate material having crystal orientation 100 [having been] is selected. At a wavelength $\lambda = 860$ nm, this material has a reflectance of about 32%, thereby ensuring sufficient quality of the generated sampled signals for a [reflectometer] reflection-type graduation.

A detailed description of subsections 4a having low reflectivity in accordance with the present invention is provided with reference to subsequent Figures 2 - 4. Figure 2 illustrates the detail marked in Figure 1 of [reflectometer] reflection-type graduation 1, in an enlarged representation. The two Figures 3a and 3b portray sectional views of the cut-away portion in Figure 2 through the indicated lines of intersection [AB] IIIa—IIIa and [CD] IIIb—IIIb, respectively.

[At this point, in] In the first specific embodiment, the present invention provides each of subsections 4a having low reflectivity with a plurality of oblique surfaces formed as V-shaped grooves 5.1 -5.10, 6.1 - 6.4, which are positioned in a second direction, [normally] perpendicular or in parallel to a first direction x. In the illustrated exemplary embodiment, the second direction corresponds to the y-direction. In Figure 3b, a longitudinal section through a subsection 4a along line of intersection [CD] IIIb—IIIb is shown, which makes the arrangement of the multiplicity of V-shaped grooves 5.1 - 5.10 [clearly] discernible.

As is likewise indicated in Figure 2, the (011) direction of silicon substrate 2 coincides with the x-direction; the (0-11) direction of silicon substrate 2 coincides with the y-direction, while the z-direction corresponds to the (100) direction.

A detailed view of single V-shaped groove 5.1 from Figure 3a is shown by Figure 4, once again in an enlarged representation; in particular the optical action of oblique surfaces, i.e., of V-shaped grooves on an incident light beam is [elucidated] shown here[, in particular].

As is discernible in Figure 4, [the] two [lateral surfaces 5.1a, 5.1b, i.e., the two oblique] surfaces 5.1a, 5.1b form an angle $\alpha \approx 72°$ with one another; angles β_a, β_b of the two lateral surfaces 5.1a, 5.1b formed with plane E amounting accordingly to $\beta_a = \beta_b \approx 54°$. Given such a geometrical dimensional design of V-shaped groove 5.1, a light beam L coming from direction of incidence IN is reflected in the illustrated manner twice off of side surfaces 5.1a, 5.1b and ultimately leaves V-shaped groove 5.1 in reflection direction OUT, which does not coincide with incident direction IN. Viewed from incident direction IN, when working with a multiple reflection of this kind, [V-groove 5.1, i.e.,] subsection 4a having a multiplicity of such V-shaped grooves 5.1 - 5.10 and 6.1 - 6.4[, respectively, appears to be] is less reflective than neighboring subsections 4b having plane surfaces, since no retroreflection of the light beams incident thereto results.

The oblique surfaces, i.e., V-shaped grooves disposed in accordance with the present invention in the less reflective subsections 4a are able to be manufactured [quite] advantageously due to the existing orientations of certain crystal planes of silicon substrate 2. Details pertaining to the method of the present invention are explained in the following description, on the basis of Figures 5a - 5h.

In the illustrated exemplary embodiment of [reflectometer] reflection-type graduation 1 according to the present invention in Figures 2, 3a, 3b, not only V-shaped grooves 5.1 - 5.10 are provided in the less reflecting subsections 4a, which extend in adjoining fashion in second direction y that is oriented normally to first direction x. Rather, disposed adjacently to each of longitudinal edges of subsections 4a is at least one further V-shaped groove 6.1 - 6.4, which extends nearly over entire length l of subsections 4a in the y-direction. Reference is especially made, in this connection, to the sectional view in Figure 3a, where the configuration of these additional V-shaped grooves 6.1 - 6.4 is more clearly apparent at the edges of the less reflecting subsections 4a.

This advantageously ensures that various subsections 4a, 4b are sharply delimited

from one another at the additional, lateral V-shaped grooves 6.1 - 6.4. These additional V-shaped grooves 6.1 - 6.4 are not essential, however, to the functioning of [reflectometer] reflection-type graduation 1 according to the present invention.

[While in the above exemplary embodiment, the oblique surfaces were designed in the less reflecting subsections as V-grooves, it] It is also optionally possible for the oblique surfaces to be formed as a multiplicity of pyramids or as pyramid-shaped depressions in [these] subsections 4a. These may be spaced at regular intervals or, however, also randomly distributed. This pyramid structure may be produced, just as the V-shaped grooves discussed above, by deeply etching the silicon substrate, for which, then, suitably modified etching masks are needed. For further details on a specific embodiment of this kind of material measuring standard according to the present invention, reference is additionally made here, for example, to the publication by I. Zubel, Silicon Anisotropic Etching in Alkaline Solutions II, Sensors and Actuators, A 70 (1998), pp. 260 -268, which is incorporated herein by reference.

One exemplary embodiment of the method according to the present invention for manufacturing a [reflectometer] reflection-type graduation is elucidated in the following on the basis of Figures 5a - 5h. Here, a method is described which is suited for manufacturing a [reflectometer] reflection-type graduation in accordance with the above described exemplary embodiment and in which the oblique surfaces are formed, accordingly, as V-shaped grooves. Such an embodiment in accordance with the present invention permits, in particular, the implementation of very fine graduation intervals.

With respect to a suitable method for manufacturing the mentioned structure having deeply etched, pyramid-shaped depressions, which are especially suited, in turn, for coarser graduation intervals, reference is [merely] again made to the above-mentioned publication.

The starting point for the method described in the following is silicon substrate 2 described in Figures 5a and 5b, in which the (011) direction coincides with the x-direction, and the (0-11) direction with the y-direction. This orientation of silicon substrate 2 ensures that the desired, straight edges are obtained.

In a first method step, silicon substrate 2 is provided with an etching mask 10, which, in this example, is composed of a chromium coating. The two views of Figures 5c and 5d show silicon substrate 2 having an applied etching mask 10. The nearly ladder-shaped etching mask 10 is applied here, on the one hand, in subsections 4b having the desired high reflectivity; on the other hand, etching mask 10 is also applied in the regions of low-reflecting subsections 4a, which are located between the V-shaped grooves to be produced, as well as in laterally bordering regions. In this connection, reference is made, in particular, to Figure 5d, which illustrates the regions of substrate material 2 covered by etching mask 10. Accordingly, merely those regions in which the V-shaped grooves are to be formed remain [not covered] uncovered by etching mask 10 on silicon substrate 2. Etching mask 10 is applied to the desired regions of silicon substrate 2 in a spatially selective manner using known lithographic processes.

Besides a chromium etching mask, it is[, of course,] possible in this [method] step to also use other materials for etching masks. For example, for this purpose, materials[,] such as TiO_2, SiO_2, suitable crystallite, Styropor globules, [etc.,] may be used to properly mask silicon substrate 2.

In the subsequent method step [-]shown in Figure 5e[-], the V-shaped grooves are etched into silicon substrate 2[, for which purpose]. This is accomplished, for example, by dipping silicon substrate 2, together with etching mask 10, [is dipped] in a suitable etching solution of potassium hydroxide (KOH) and isopropanol (H_7C_3OH). Of course, other etching media may also be used for the requisite anisotropic etching process; for example, at this point, known methods, such as reactive ion etching, [etc.,] could also be employed. The desired V-shaped grooves are obtained during the anisotropic deep-etching process due to the different etching rates in silicon substrate 2 for the various crystal-plane orientations. Thus, the etching rate in the (100) direction is approximately 100 times greater than the etching rate in the (111) direction. In this connection, the etching process is continued until the resulting oblique edges or side surfaces have converged, i.e., until the V-shaped groove [described] shown in Figure 4 is fully formed. The V-shaped groove structures [which] that ultimately result in the process are discernible in the side view of Figure 5f. A plan view of a part of the material measuring standard in this process stage is shown in Figure 5g.

[Finally, all that is still removed is merely] After etching, the etching mask 10 is removed from substrate 2. This may be done, for instance, using known using wet chemical etching processes. A section through the then resulting structure is shown in Figure 5h.

The last method step is not needed in every case; particularly when the intention is for reflecting etching mask 10 to remain in the higher reflecting subsections 4b. In the case of a chromium etching mask, the chromium etching mask may remain, for example, in subsections 4b having high reflectivity. This is especially practical when a particularly high reflectivity of subsections 4b is optionally required. In principle, however, the reflectance of the silicon substrate surface, already mentioned above, suffices.

A particular benefit, in this context, of the above described method is that virtually no undercut-etching of the etching mask results, so that a mechanically stable graduated-scale structure is obtained. Furthermore, this method renders possible the manufacturing of especially fine graduation structures.

A scanning electron-microscopic picture of a first specific embodiment of the [reflectometer] reflection-type graduation according to the present invention, as described at the outset, is depicted in Figure 6. In this context, the low reflecting subsections exhibit the above described V-shaped groove structure.

Figure 7 shows the scanning electron-microscopic picture of a detail of a second variant of the material measuring standard according to the present invention. Evident in Figure 7 is a portion of a low-reflecting subsection, where the deeply etched, oblique surfaces, as indicated above, are formed by a multiplicity of irregularly distributed pyramid-shaped depressions.

[It goes without saying that the above description merely elucidates possible exemplary] While the foregoing description and drawings represent the preferred embodiments[, i.e., within the scope] of the present invention, [variations thereof are also conceivable] it will be apparent to whose skilled in the art that various changes and modifications may be made therein without departing from the true spirit and scope of the present invention.

Abstract

A reflection-type graduation having a silicon substrate. The silicon substrate has first subsections formed thereon. Each of the first subsections has etched oblique surfaces. The surfaces are positioned so that light beams directed incident to the surfaces cause no retroreflection. The substrate also includes second subsections having relatively higher reflecting properties as compared to the first subsections. The first subsections and second subsections are alternatively disposed on the substrate in a first direction.